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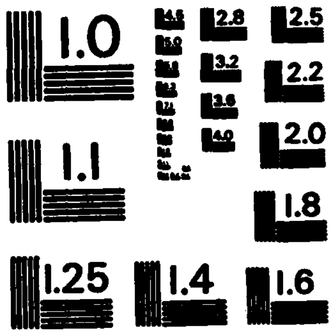
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USER'S GUIDE FOR COMPUTER PROGRAM HEAVE

by

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The program HEAVE is a one-dimensional computer program for approximate analysis of vertical movements of swelling foundation soils beneath permanent structures caused by changes in vertical loads and/or the moisture profile. The program is applicable to slab, long continuous, and circular shaft foundations. Results of both one-dimensional consolidometer swell tests and soil suction tests may be used in HEAVE.

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20. ABSTRACT (Continued).

The program considers effects of soil overburden pressures and structural loads, heterogeneous soils, and saturated or hydrostatic equilibrium moisture profiles on the computed heave. An arbitrary final soil suction profile may also be input if soil suction results are available. Differential heave may be estimated by comparing heaves computed for different soil strata and vertical loads.

HEAVE can estimate the movement of circular drilled shaft foundations, the maximum tension force in circular shafts from heave of surrounding swelling soil, and the restraining force provided by the underream (a bell or enlargement of the shaft base). Upward movement is assumed negligible if restraint exceeds the uplift thrust from surrounding swelling soil. Estimates of shaft movement can be made for moisture migrating down the shaft from the ground surface, moisture migrating from an intermediate zone such as from a relatively thin, pervious sandy stratum, and moisture migrating upward from below the base of the shaft such as from capillary rise of a rising water table.

Preface

This computer program and user's guide were prepared under RDT&E Work Unit AT40/EO/004, "Foundations on Swelling Soils," sponsored by the Office, Chief of Engineers, U. S. Army. The investigation on which this report is based was conducted during FY 81.

This user's guide was prepared by Dr. L. D. Johnson, Research Group (RG), Soil Mechanics Division (SMD), Geotechnical Laboratory (GL), U. S. Army Engineer Waterways Experiment Station (WES) under the general supervision of Mr. C. L. McAnear, Chief, SMD, and Dr. W. F. Marcuson III, Chief, GL. Dr. P. F. Hadala, Assistant Chief, GL, Dr. E. B. Perry, RG, SMD, and Mr. G. B. Mitchell, Chief, EG, SMD, reviewed the report.

The Commander and Director of WES during preparation of this report was COL Tilford C. Creel, CE. The Technical Director was Mr. Fred R. Brown.

<u>Contents</u>

Conversion Factors, U. S. Customary to Metric (SI) Units of Measurement

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
pounds (force) per square foot	47.88026	pascals
square feet	0.09290304	square metres
tons (force)	8896.444	newtons
tons (force) per square foot	95.76052	kilopascals
tons (mass) per cubic foot	320.3692	kilograms per cubic metre

USER'S GUIDE FOR COMPUTER PROGRAM HEAVE

Purpose and Scope

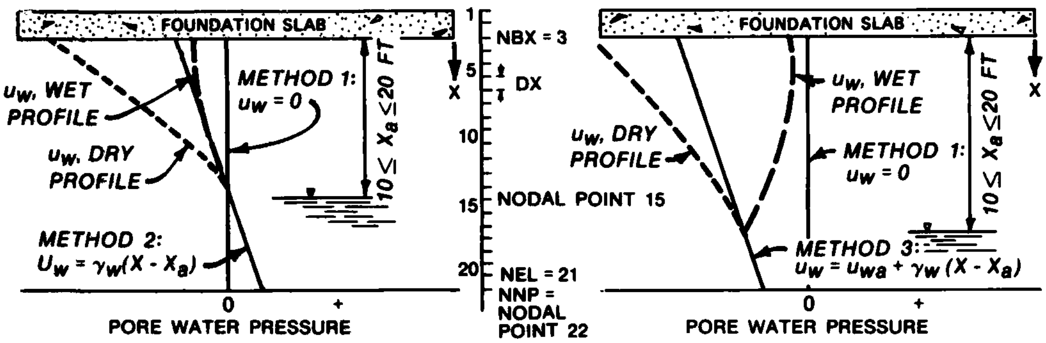
1. The purpose of this user's guide is to document the computer program HEAVE, which was developed to assist the design engineer in determining optimum foundations in expansive soils. This program may be used to estimate vertical foundation movements for the methodology described in TM 5-818-7 (Headquaters, Department of the Army 1982). The program HEAVE approximates potential vertical movements beneath the center or corner of rectangular slab foundations, beneath the central axis or edge of long (or strip) continuous footings, and beneath the center of circular deep shaft foundations. Vertical movement may also be computed for soils beneath these foundations constructed in excavations and for soils adjacent to the foundation not confined by structural loads. Foundation movement estimated by HEAVE has been checked by comparison with field test sections (Johnson 1981) and practical application to existing structures.

2. Structural loads are assumed to be transferred to the supporting soils, and the soil-bearing capacity is assumed not to be exceeded beneath the foundations. Computation of potential heave beneath the circular deep shaft foundation also considers the restraining force of underreams and the uplift force of swelling adjacent soil. Laboratory test data from consolidation swell or soil suction tests are used in the program HEAVE.

Methodology of Computations

Foundation movement

3. The potential total vertical heave at the bottom of the foundation as shown in Figure 1 is determined by



a. Shallow Groundwater Level　　　　b. Deep Groundwater Level

Figure 1. Schematic for computation of vertical movement by program HEAVE

$$\Delta H = N \cdot DX \sum_{i=NBX}^{i=NEL} DELTA(i) = N \cdot DX \sum_{i=NBX}^{i=NEL} \frac{e_f(i) - e_o(i)}{1 + e_o(i)} \quad (1)$$

where

ΔH = potential vertical heave at the bottom of the foundation, ft*

N = fraction of volumetric swell that occurs as heave in the vertical direction

DX = increment of depth, ft

NEL = total number of elements

NBX = number of nodal point at bottom of the foundation

DELTA(i) = potential volumetric swell of soil element i , fraction

$e_f(i)$ = final void ratio of element i

$e_o(i)$ = initial void ratio of element i

The ΔH is the potential vertical heave beneath a flexible, unrestrained foundation. The bottom nodal point NNP = NEL + 1 is often set at the depth of the active zone. The program HEAVE assumes that N = 1 . The fraction N should be 1 for one-dimensional consolidometer swell test results. The soil suction test results tend to provide an upper bound

* A table of factors for converting U. S. customary units of measurements to metric (SI) units is presented on page 3.

estimate of the maximum in situ heave for intact soil (N = 1) in part because the soil suction tests are performed without the horizontal restraint on soil swell that exists in the field and during consolidometer tests. Dividing the heave by 3 (N = 1/3) will tend toward a lower bound estimate for fissured soil (Richards 1967). Differential heave may be estimated by comparing the computed heaves for different soil strata, vertical loads, and equilibrium moisture profiles.

4. The program HEAVE computes the difference in void ratio Δe (i.e., $e_f - e_o$) from consolidometer swell test results of each soil layer by

$$\Delta e = c_s \log \frac{\sigma_s}{\sigma'_v} \tag{2}$$

where

c_s = swell index

σ_s = swell pressure, tsf

σ'_v = vertical effective pressure, tsf

The compression index c_c is substituted for c_s if σ'_v exceeds σ_s.

5. The program HEAVE computes Δe from soil suction test results of each soil layer by

$$\Delta e = C_\tau \log \frac{\tau^o_{mo}}{\tau^o_{mf}} \tag{3}$$

where

$C_\tau = \alpha G_s/100B$, suction index

α = compressibility factor

G_s = specific gravity

B = slope soil suction parameter

τ^o_{mo} = initial matrix suction without surcharge pressure, tsf

τ^o_{mf} = final matrix suction without surcharge pressure, tsf

The compressibility factor α is the ratio of the change in volume for a corresponding change in water content and can be found by the procedure in TM 5-818-7. The B parameter is the slope of the matrix soil

suction-water content relationship expressed as

$$\log \tau_m^o = A - Bw \tag{4}$$

where

A = ordinate intercept soil suction parameter, tsf

w = water content, percent dry weight

6. The matrix suction τ_m^o is assumed to be related to the pore water pressure by

$$\tau_m^o = -u_w + \alpha\sigma_m \tag{5}$$

where

u_w = pore water pressure, tsf

σ_m = total mean normal confining pressure, tsf

The total mean normal confining pressure σ_m is given by

$$\sigma_m = \frac{(1 + 2K_T)}{3} \sigma_v \tag{6}$$

where

K_T = ratio of total horizontal to vertical stress in situ

σ_v = total vertical pressure, tsf

Equilibrium pore water pressure

7. The accuracy of the estimates of the potential vertical heave in simulating the maximum in situ heave depends heavily on the ability to properly estimate the equilibrium pore water pressure profile. Figure 1 indicates examples of extremes that can occur in the seasonal moisture profile. Seasonal heave between extreme wet and dry moisture profiles can be estimated by taking the difference between heaves computed for both extreme wet and dry profiles (Figure 1a), or the sum of the settlement for the wet profile and heave of the dry profile (Figure 1b). The program HEAVE considers the three following profiles illustrated in Figure 1.

8. Saturated profile. The saturated profile, Method 1, assumes that the in situ pore water pressure is zero within the active zone X_a of moisture change and heave

$$u_w = 0 \tag{7}$$

9. Hydrostatic I. The hydrostatic I profile, Method 2, assumes that the pore water pressure at depth X becomes more negative with increasing vertical distance above the groundwater level in proportion to the unit weight of water

$$u_w = \gamma_w(X - X_a) \tag{8}$$

where γ_w is the unit weight of water (0.0312 tcf).

10. Hydrostatic II. The hydrostatic II profile, Method 3, is similar to the hydrostatic I profile except that a shallow water table does not exist. The negative pore water pressure of this profile also becomes more negative with increasing vertical distance above the bottom of the active zone X_a in proportion to the unit weight of water

$$u_w = u_{wa} + \gamma_w(X - X_a) \tag{9}$$

where u_{wa} is the negative pore water pressure in tons per square foot at depth X_a in feet.

Depth of the active zone

11. The depth of the active zone X_a is defined as the least soil depth above which changes in water content and heave occur because of climate and environmental changes after construction of the foundation. The depth X_a may be estimated by procedures described in TM 5-818-7. Predictions of shaft movement can be made for the three cases of active depths shown in Table 1. The three cases are differentiated in program HEAVE by denoting the depths X_a and X_f where X_f is the depth of inactive or nonswelling soil overlying the swelling soil.

Effect of uplift forces

12. The program HEAVE ignores uplift thrust of swelling soils adjacent to slab or long continuous footings. The uplift thrust of adjacent swelling soils on deep foundations (Figure 2) is determined for the assumption that interaction of stresses between skin friction and end bearing is negligible and is expressed as

$$Q_u = \pi D_s \int_0^{L_n} f_s \, dL \qquad (10)$$

where

Q_u = maximum uplift thrust on perimeter of shaft, tons

D_s = diameter of shaft, ft

L_n = thickness of the swelling layer moving up relative to the shaft, ft

f_s = skin resistance, tsf

dL = differential increment of shaft length L, ft

The point n in Figure 2 is the neutral point. The value of L_n should be approximately equal to the depth X_a. The maximum tension force T in the shaft is estimated from

$$T = Q_w - Q_u \qquad (11)$$

where Q_w is the loading force from the structure and includes the weight of the shaft.

13. The skin friction f_s is evaluated by

$$f_s = c_a + K\sigma'_v \tan \phi_a \qquad (12)$$

where

c_a = adhesion, tsf

K = ratio of horizontal to vertical effective stress

σ'_v = vertical effective stress, tsf

ϕ_a = angle of friction between the soil and shaft, deg

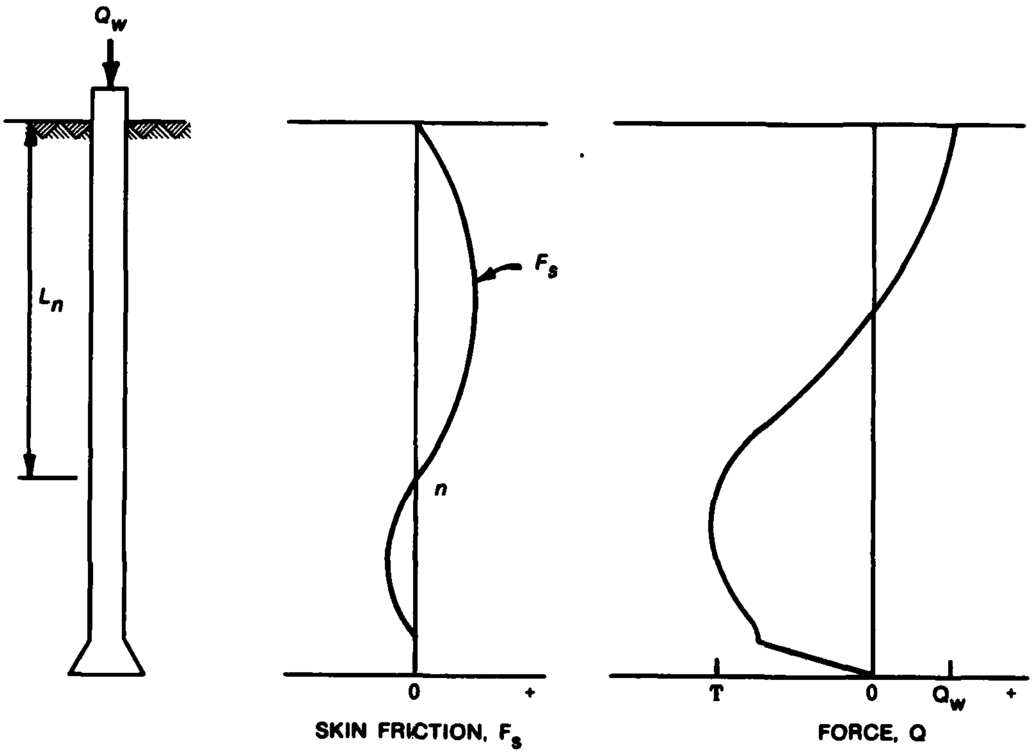


Figure 2. Distribution of load from uplift of swelling soil

If drained strength data are available, c_a is often set equal to zero and ϕ_a set equal to the effective angle of internal friction ϕ' of remolded soil or the strength at large strain. The skin friction based on undrained strength data is given by

$$f_s = \alpha_f c_u \tag{13}$$

where

α_f = reduction coefficient

c_u = undisturbed undrained shear strength, tsf

14. The program HEAVE computes the minimum percent steel A_s required if ASTM A 615 (1976) Grade 60 steel is used by the equation

$$\text{Percent } A_s = -0.03 \frac{T}{D_s^2} \tag{14}$$

where

T = negative tension force, tons

D_s = shaft diameter, ft

15. The bearing capacity of the soil above the underream is calculated in program HEAVE by the equation

$$q_b = cN_c + \sigma'_v N_q \tag{15}$$

where

q_b = bearing capacity above the underream, tsf

c = cohesion, tsf

σ'_v = effective vertical overburden pressure, tsf

N_c, N_q = bearing capacity factors

If undrained strength data are used, then $N_c = 7$ and $N_q = 0$. The cohesion c is the undrained shear strength c_u . If drained strength data are used, then the bearing capacity factors are calculated by program HEAVE by the following equations (Vesic 1977):

$$N_c = \cot \phi'(N_q - 1) \tag{16}$$

$$N_q = (1 + \tan \phi')e^{\tan \phi'} \tan^2 \left(45 + \frac{\phi'}{2}\right) \tag{17}$$

where ϕ' is the effective angle of shearing resistance. The cohesion c is the effective cohesion in Equation 15. Equation 17 is indicative of failure by the Terzaghi local shear mechanism and tends to represent a lower limit of the bearing capacity factor N_q .

16. The soil suction model described in TM 5-818-7 may also compute the effect of uplift as well as the consolidometer swell model if the swell pressure is input for each soil layer. If the swell pressure is not input, the program assumes that the swell pressure is given by the initial soil matrix suction, an assumption that can greatly exceed the swell pressure. Computed shaft uplift movements will be an upper limit because the shaft stiffness is assumed equal to the soil stiffness.

Bearing capacity

17. The program HEAVE computes the bearing capacity of the foundation soil assuming that Equations 15-17 are applicable. If undrained strength data are used, $N_c = 9$. The message

BEARING CAPACITY OF   TSF EXCEEDED FOR ELEMENT

is printed if loading pressures exceed the computed bearing capacity of the given element.

Computer Program

18. The program consists of a main routine and five subroutines. The main routine feeds in the input data, calculates effective overburden pressure, determines the restraining force Q_r for a deep shaft foundation, and computes the foundation force beneath the shaft and tension force from uplift of adjacent swelling soils. The subroutine MECH applies the mechanical model for prediction of potential heave using the results of consolidometer swell tests. The subroutines SUCT and HSUCT apply the soil suction model. The subroutine PSAD sets up the proper depths in the soil profile for calculation of heave. The subroutine SLAB sets up the bearing pressure for slab and long continuous footings. The program is set to consider up to 10 different soils and a maximum of 80 soil elements. The capacity of the program may be increased by adjusting the PARAMETER statements.

Input data

19. The program was prepared for time-sharing on the Honeywell series G600 computer. The input data are entered in free field format as illustrated in Table 2. Descriptions of the input data are given in Table 3.

Output data

20. The output data are illustrated in Table 4. Descriptions of the output data are given in Table 5.

Example Applications

21. Three example problems are provided. All use the soil properties given in Table 6.

Slab in excavation

22. Table 7 illustrates the input data for a slab in an excavation 12 ft deep (Figure 3). The groundwater DGWT is 22 ft below ground surface or 10 ft below the slab. The mechanical model was used for a 100- by 100-ft slab. The output data are provided in Table 7 for a loading pressure of 0.072 tsf assuming a saturated final pore pressure profile at the center. Heave beneath the slab is 0.25 ft. Heave adjacent to the slab in soil above 12 ft of depth is 0.18 ft.

Long continuous footing

23. Table 8 illustrates the input data for an infinitely long continuous footing 100 ft wide on the ground surface (Figure 4) using the mechanical model. The groundwater level is 8 ft below the footing. The output data are provided in Table 8 for a loading pressure of 0.072 tsf assuming a saturated final pore pressure profile. The heave beneath this footing is 0.14 ft.

Circular shaft

24. Table 9 illustrates the input data for a circular shaft 30 ft deep and 2 ft in diameter with a 3-ft-diam underream (Figure 5) using the soil suction model with drained strength data. The active zone extends from the ground surface to 10 ft below the base of the shaft. A 10-ton loading force Q_w is placed on the shaft. The output data are provided in Table 9 assuming a saturated profile for the full 40 ft of active depth, X_a . The shaft heave of 1.16 ft is the maximum that a cracked shaft could rise excluding subsoil movement, while one-third of this heave or 0.4 ft is more likely in a fissured soil. The actual shaft heave will be less if no fracture results in the shaft. The maximum soil heave adjacent to the shaft is 1.3 ft. A gap could open beneath the bottom of the shaft. The maximum tension force of -166.5 tons will require 1.3 percent steel in the 2-ft-diam shaft.

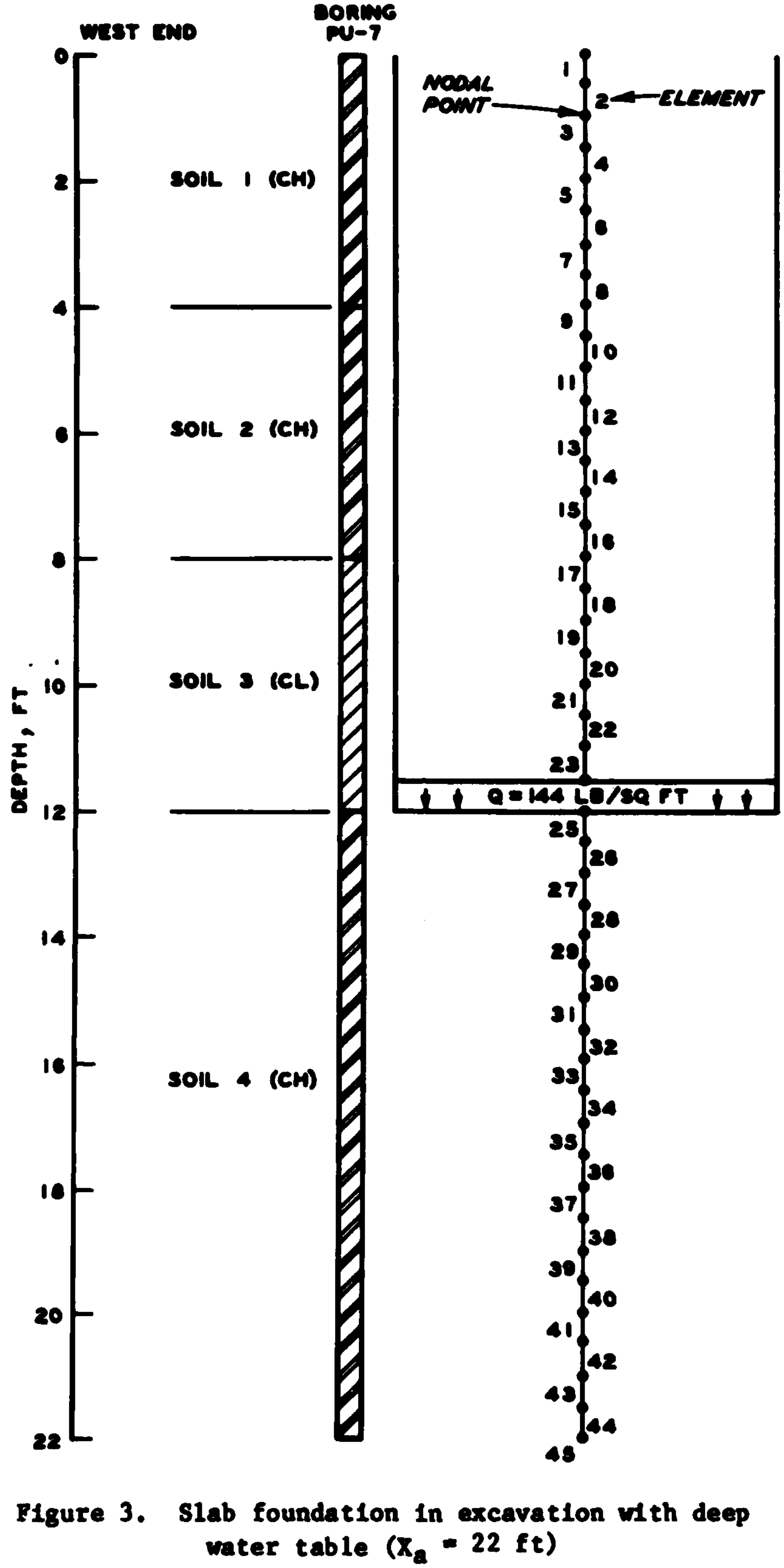


Figure 3. Slab foundation in excavation with deep water table (X_a = 22 ft)

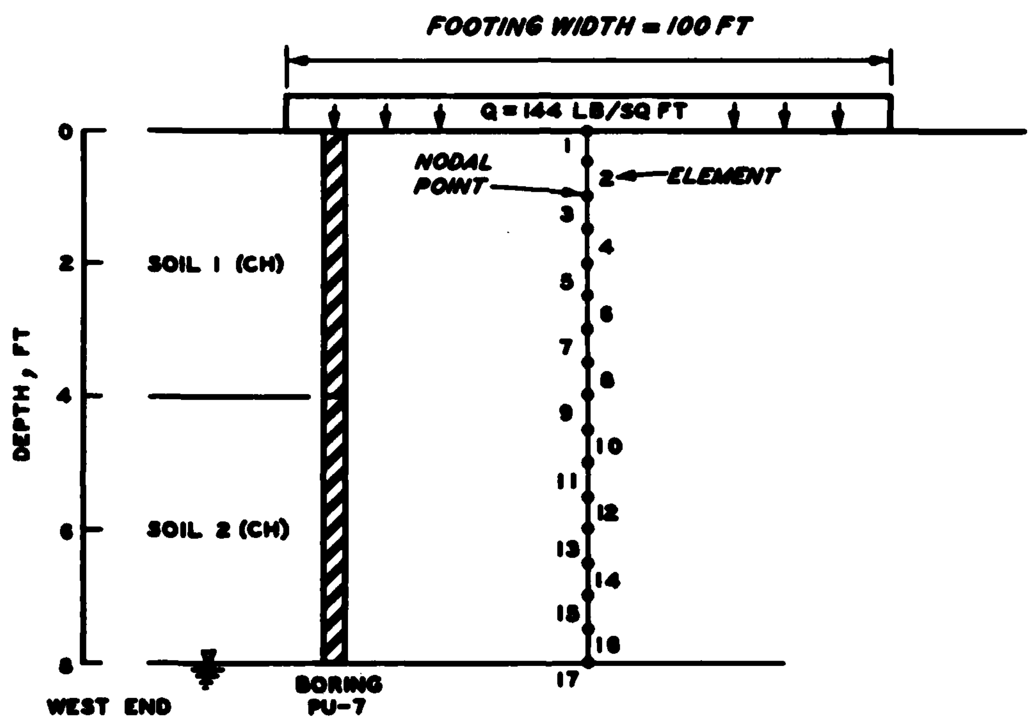


Figure 4. Long continuous footing at ground surface

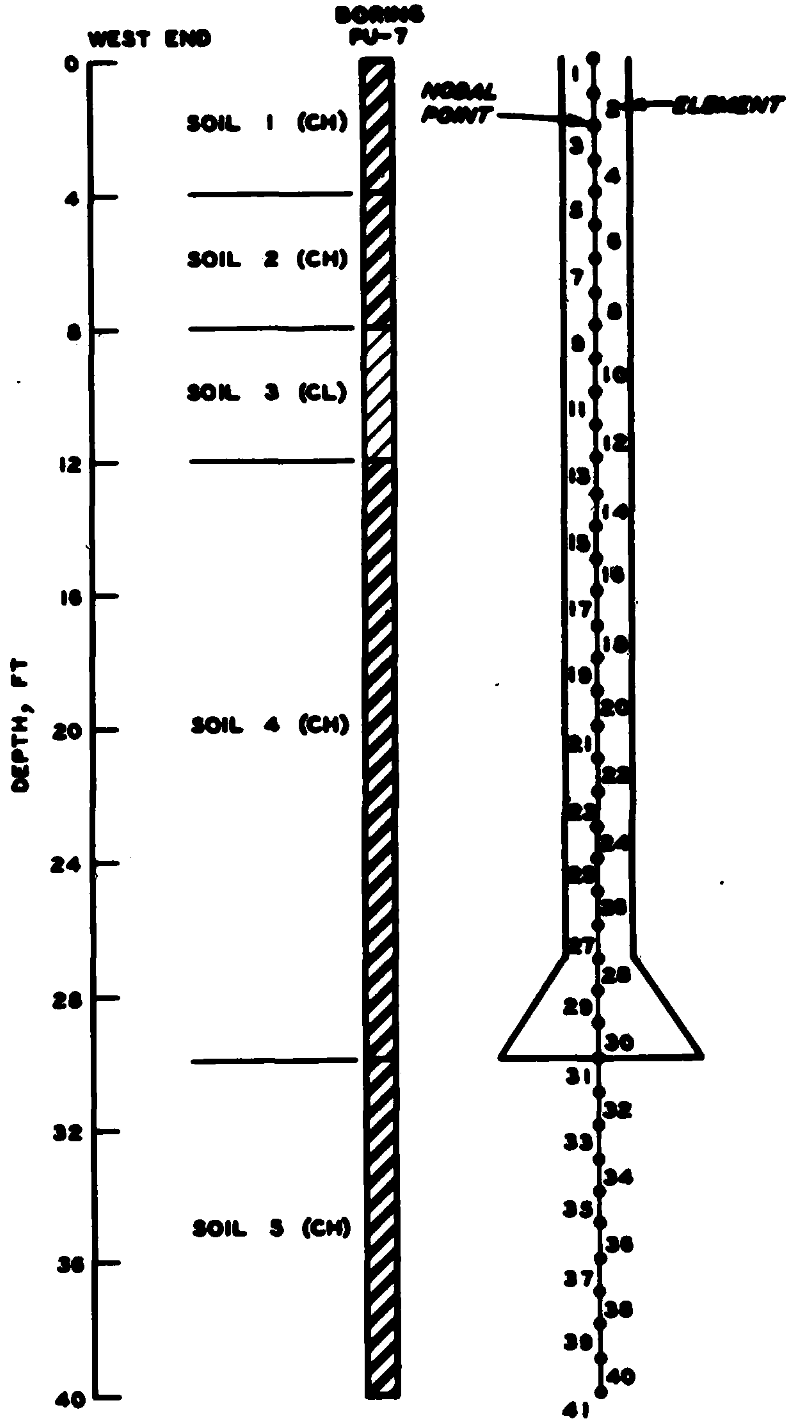


Figure 5. Shaft foundation 30 ft deep with active zone from ground surface to 40 ft deep

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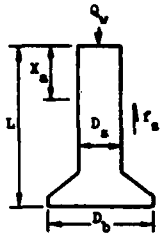
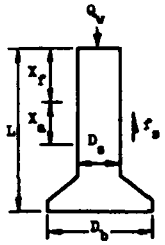
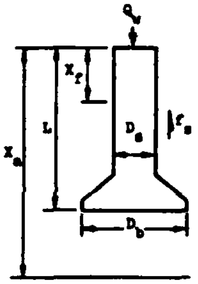
Vesic, A. S. 1977. "Design of Pile Foundations," National Cooperative Highway Research Program, Synthesis of Highway Practice No. 42, Transportation Research Board, National Research Council, Washington, D. C.

Table 1

Prediction of Shaft Movement

Case	Mechanism of Uplift	Sketch	Equations*
1	The shaft is lifted when the uplift force Q_u given by $\sigma_s-\sigma'_v$ times the area A_{act} over which σ_s is active exceeds the restraining force Q_r. The shaft stops lifting when $Q_u < Q_r$ or the skin friction f_s times A_{act} is less than Q_r		1. $\Delta_{shaft} \le 0$ if $(\sigma_s - \sigma'_v)A_{act} \le Q_r$ 2. $\Delta_{shaft} \le 0$ if $f_s A_{act} \le Q_r$ 3. $\Delta_{shaft} = X_a c_s \log \frac{\sigma_s}{Q_r/A_{act}}$ if $\sigma_s > \frac{Q_r}{A_{act}} > \sigma'_v$ 4. $\Delta_{shaft} = X_a c_s \log \frac{\sigma_s}{\sigma'_v}$ if $\sigma_s > \sigma'_v > \frac{Q_r}{A_{act}}$ 5. $\Delta_{soil} = X_a c_s \log \frac{\sigma_s}{\sigma'_v}$ 6. $A_{act} = X_a \pi D_s$ 7. $Q_r = Q_v + f_s(L - X_a)\pi D_s + q_b \frac{\pi}{4}(D_b^2-D_s^2)$
2	Same as Case 1 except that soil from the ground surface to depth X_f does not swell and does not contribute to uplift. Case 2 converged to Case 1 when $X_f = 0$.		Same as Case 1
3	The shaft is lifted a distance equal to the vertical swelling of the soil beneath the shaft as wetting ascends to the base of the shaft. The shaft is lifted further as soil wetting ascends above the base when uplift force Q_u exceeds the restraining force Q_r. The shaft stops lifting when $Q_u < Q_r$ or $f_s A_{act} < Q_r$.		1. $\Delta_{shaft} \le 0$ if $(\sigma_s - \sigma'_v)A_{act} < Q_r$ 2. $\Delta_{shaft} \le 0$ if $f_s A_{act} \le Q_r$ 3. $\Delta_{shaft} = (X_a - L)c_s \log \frac{\sigma_s}{\sigma'_v} + (L - X_f)c_s \log \frac{\sigma_s}{Q_r/A_{act}}$ if $\sigma_s > \frac{Q_r}{A_{act}} > \sigma'_v$ 4. $\Delta_{shaft} = (X_a - X_f)c_s \log \frac{\sigma_s}{\sigma'_v}$ if $\sigma_s > \sigma'_v > \frac{Q_r}{A_{act}}$ 5. $\Delta_{soil} = (X_a - X_f)c_s \log \frac{\sigma_s}{\sigma'_v}$ 6. $A_{act} = (L - X_f)\pi D_s$ 7. $Q_r = Q_v + q_b \frac{\pi}{4}(D_b^2-D_s^2)$

* Notation:
- A_{act} = area over which swell pressure σ_s is active, ft^2
- c_s = swell index or suction index C_τ, Equations 2 and 3
- D_b = diameter of underreamed base, ft
- D_s = diameter of shaft, ft
- f_s = skin friction found by Equations 12 and 13, tsf
- L = length of shaft, ft
- q_b = bearing capacity of soil above underream, tsf
- Q_r = force restraining uplift force of swelling soil, tons
- Q_u = uplift force $\left(\sigma_s - \sigma'_v\right)A_{act}$, tons
- Q_v = structural load on shaft including shaft weight, tons
- X_a = depth or thickness of active zone, ft
- X_f = depth of nonswelling soil from ground surface, ft
- Δ_{shaft} = movement of shaft, ft
- Δ_{soil} = movement of soil surrounding shaft, ft
- σ_s = soil swell pressure, tsf
- σ'_v = effective overburden pressure, tsf

Table 2

Input Data Format

Step	Data
1	The program will print: TITLE? = . Input description of the problem
2	The program will print after carriage return: NPROB,NSUCT,NBPRES,NNP,NBX,NMAT,DX = . Input the above variables (see Table 3 for definitions)
3	The program will print after carriage return: M,G,WC,EO,C,PHI,K = . Input the above variables
4A	If NSUCT = 0 , the program will print after carriage return: M,SP,CS,CC = . Input the above variables,
4B	If NSUCT = 1 , the program will print after carriage return: M,A,B,ALPHA,KT,PI,SP = . Input the above variables. If ALPHA left blank, then $\alpha = 0$ for $PI \le 5$ $\alpha = 0.0275PI - 0.125$ for $5 < PI < 40$ $\alpha = 1$ for $PI \ge 40$ If SP left blank, the swell pressure will be assumed the initial matrix soil suction
	The program will repeat steps 3 and 4 until all soils from M = 1 to M = NMAT are input
5	The program will print after carriage return: ELEMENT,NO. OF SOIL = . Input 1,1 = . Input element,2 for elements in increasing order for each increase in soil type M = . Input NEL,NMAT as the last and deepest element for soil type M = NMAT
6	The program will print after carriage return up to NPROB : XA,XF,DGWT,IOPTION,NOPT = . Input the above variables
7A	If NBPRES ≠ 1, the program will print after carriage return: Q,BLEN,BWID,LOCATION(CENTER=0,EDGE/CORNER=1) = . Input the above variables
7B	If NBPRES = 1, the program will print after carriage return: PLOAD,AF,DP,DB = . Input the above variables

Table 3

Description of Input Data

Symbol	Step	Description
		Type of Problem
NPROB	2	Number of cases with the same soil profile. Loads and foundation dimensions can be varied
NSUCT	2	Option for model: =0 for consolidation swell (MECH) model; =1 for soil suction model
NBPRES	2	Option for foundation: =1 for circular or shaft; =2 for rectangular slab; =3 for long continuous
NNP	2	Total number of nodal points, NEL + 1
NBX	2	Number of nodal point at the bottom of the foundation
NMAT	2	Total number of different soil layers
DX	2	Increment of depth, ft
		Physical Properties
M	3	Number of soil layer
G	3	Specific gravity G_s of soil layer M
WC	3	Initial water content w_o of soil layer M , percent
EO	3	Initial void ratio e_o of soil layer M
C	3	Soil effective cohesion c' or undrained shear strength c_u , tsf
PHI	3	Effective angle of internal friction ϕ' ; = 0 if $C = c_u$
K	3	Ratio of horizontal to vertical effective pressure K.K = 1.0 if left blank
		Swell Characterization by the Consolidation Swell (MECH) Model
M	4A	Number of soil layer
SP	4A	Swell pressure σ_s of soil layer M , tsf
CS	4A	Swell index c_s of soil layer M
CC	4A	Compression index c_c of soil layer M
		Swell Characterization by the Soil Suction (SUCT) Model
M	4B	Number of soil layer
A	4B	Intercept of log suction and water content relationship of soil layer M , tsf
B	4B	Slope of log suction and water content relationship of soil layer M
ALPHA	4B	Compressibility factor α of soil layer M
KT	4B	Ratio of total horizontal to vertical pressure K_T of soil layer M
PI	4B	Plasticity index PI of soil layer M , percent
SP	4B	Swell pressure σ_s of soil layer M , tsf. $\sigma_s = \tau_m^o$ if left blank
		Element Characterization
ELEMENT	5	Number of soil element
NO. of Soil	5	Number of soil layer M
NEL	5	Total number of soil elements
NMAT	5	Total number of soil layers
		Equilibrium Moisture Profile
XA	6	Depth of the active zone X_a , ft. Movement beneath the foundation assumes the equilibrium moisture profile extends *down to the bottom nodal point NNP*
XF	6	Depth from ground surface to the depth that the active zone begins X_f , ft
DGWT	6	Depth to the groundwater table, ft. DGWT is set internally to the depth of nodal point NNP if IOPTION > 1
IOPTION	6	Equilibrium moisture profile: =0 for saturation (Equation 7); =1 for hydrostatic I (Equation 8); to simulate Equation (9), set IOPTION = 1 and DGWT = $X_a - u_a/\gamma_w$ or IOPTION = 2 if NSUCT = 1; if IOPTION = 3 and NSUCT = 1, the final total soil suction without surcharge pressure τ_m^o is input for each soil layer
NOPT	6	Option for amount of output: =0 for forces (if NBPRES = 1) and total heave; =1 for forces, total heave, and the fraction and excess pore pressure at each depth interval
		Loading and Dimensions of Foundation
Q	7A	Foundation and superstructure pressure, tsf
BLEN	7A	Radius of circular foundation (NBPRES = 1); length of slab (NBPRES = 2), =0.0 for long continuous (NBPRES = 3), ft
BWID	7A	0.0 for circular foundation; width of slab; width of long continuous footing, ft
LOCATION	7A	=0 for center of rectangular slab or long continuous footing; =1 for corner of slab or edge of long continuous footing. Not used for circular foundation where only center results printed
PLOAD	7B	Loading force on circular shaft including weight of shaft Q_w , tons
AF	7B	Reduction factor of skin friction term α_f (Equation 13)
DP	7B	Diameter of shaft D_s , ft
DB	7B	Diameter of base or underream D_b , ft

Table 4

Output Data Format

Line	Data		
	NBPRES ≠ 1		
1	(If NOPT = 1) ELEMENT DEPTH,FT DELTA HEAVE,FT EXCESS PORE PRESSURE,TSF		
2	SOIL HEAVE NEXT TO FOUNDATION EXCLUDING SUBSOIL=		FEET
3	SUBSOIL MOVEMENT=		FEET
4	TOTAL SOIL MOVEMENT=		FEET
	NBPRES = 1		
1	FORCE RESTRAINING UPLIFT=	EXCESS=	TONS
2	SHAFT HEAVE (EXCLUDING SUBSOIL MOVEMENT)=		FEET
3	FORCE AT BOTTOM OF SHAFT=	TENSION= AREA STEEL=	TONS PERCENT
4	(If NOPT = 1) ELEMENT DEPTH,FT DELTA HEAVE,FT EXCESS PORE PRESSURE,TSF		
5	SOIL HEAVE NEXT TO FOUNDATION EXCLUDING SUBSOIL=		FEET
6	SUBSOIL MOVEMENT=		FEET
7	TOTAL SOIL MOVEMENT=		FEET
8	TOTAL SHAFT MOVEMENT=		FEET

Table 5

Description of Output Data

Symbol	Description
ELEMENT	Number of element
DEPTH,FT	Depth of center of element, ft
DELTA HEAVE,FT	Heave of increment (element) ΔH , ft
EXCESS PORE PRESSURE,TSF	Initial negative pore pressure exceeding equilibrium pressure,tsf
SOIL HEAVE NEXT TO FOUNDATION EXCLUDING SUBSOIL	Movement of adjacent soil above bottom of foundation, ft
SUBSOIL MOVEMENT	Movement of soil beneath foundation, ft
TOTAL SOIL MOVEMENT	Total heave of soil adjacent to foundation, ft
FORCE RESTRAINING UPLIFT	Force restraining uplift Q_r , tons
EXCESS	$Q_r - Q_u$ where Q_u = uplift force, tons
SHAFT HEAVE (EXCLUDING SUBSOIL MOVEMENT)	Movement of shaft excluding soil movement beneath shaft, ft
FORCE AT BOTTOM OF SHAFT	Force exerted on soil beneath the shaft (positive quantity), tons
TENSION	Maximum tension in shaft (negative quantity), tons
AREA STEEL	Percent steel from Equation 14 assuming ASTM A615 Grade 60 steel is used. The minimum steel should be 1 percent although the computed steel may be less.
TOTAL SHAFT MOVEMENT	Total movement of shaft, ft

Note: Positive values represent upward movement or compression force while negative values represent downward movement or tension force.

Table 6

Soil Properties for Example Problems

Depth, ft	Strength Parameters										Suction Parameters				Atterberg Limits	
	G_s	w_o, %	e_o	c_u	c, tsf	ϕ, deg	K	σ_s, tsf	c_s	c_c	A	B	α	K_T	LL	PI
0-4	2.70	23.0	0.800	0.5		20	1.0	2.20	0.045	0.27	6.75	0.25	1.00	1.0	57	39
4-8	2.70	25.0	0.745	0.5		20	1.0	0.66	0.045	0.27	6.75	0.25	1.00	1.0	60	40
8-12	2.75	30.0	0.825	1.0		30	1.0	0.70	0.030	0.27	5.04	0.17	0.26	1.0	49	14
12-30	2.76	29.0	0.828	2.0	1.0	10	2.0	2.40	0.052	0.20	5.86	0.18	1.00	2.0	75	55
30-	2.76	29.0	0.828	2.0	1.0	10	2.0	2.85	0.048	0.13	6.14	0.19	1.00	2.0	80	55

Table 7

Input and Output Data for Slab in Excavation

Input Data

```
SYSTEM ?FORT
OLD OR NEW-OLD HEAVE
READY
*RUN
=SLAB IN EXCAVATION, DGWT = 22 FT     MECH
NPROB,NSUCT,NBPRES,NNP,NBX,NMAT,DX
=3,0,2,45,25,4,.5
M,G,WC,EO,C,PHI,K
=1,2.7,23.,.8,,,
M,ALL,SP,CS,CC
=1,57.,2.2,.045,.27
M,G,WC,EO,C,PHI,K
=2,2.7,25.,.745,,,
M,ALL,SP,CS,CC
=2,60.,.66,.045,.27
M,G,WC,EO,C,PHI,K
=3,2.75,30.,.825,,,
M,ALL,SP,CS,CC
=3,49.,.7,.03,.27
M,G,WC,EO,C,PHI,K
=4,2.76,29.,.828,,,
M,ALL,SP,CS,CC
=4,75.,2.4,.052,.2
ELEMENT,NO. OF SOIL
=1,1
=9,2
=17,3
=25,4
=44,4

XA,XF,DGWT,IOPTION,NOPT
=22.,.0,22.,0,1

Q,BLEN,BWID,LOCATION(CENTER=0,EDGE/CORNER=1)
=.072,100.,100.,0
```

(Continued)

Table 7 (Concluded)

Output Data

ELEMENT	DEPTH,FT	DELTA HEAVE,FT	EXCESS PORE PRESSURE,TSF
1	0.25	0.05459	2.18559
2	0.75	0.04266	2.15676
3	1.25	0.03712	2.12793
4	1.75	0.03346	2.09910
5	2.25	0.03073	2.07027
6	2.75	0.02856	2.04145
7	3.25	0.02674	2.01262
8	3.75	0.02519	1.98379
9	4.25	0.01107	0.41426
10	4.75	0.00977	0.38404
11	5.25	0.00860	0.35382
12	5.75	0.00755	0.32360
13	6.25	0.00658	0.29338
14	6.75	0.00570	0.26316
15	7.25	0.00488	0.23294
16	7.75	0.00411	0.20272
17	8.25	0.00258	0.21231
18	8.75	0.00215	0.18170
19	9.25	0.00174	0.15109
20	9.75	0.00135	0.12049
21	10.25	0.00098	0.08988
22	10.75	0.00063	0.05927
23	11.25	0.00030	0.02866
24	11.75	0.00437	0.32068
25	12.25	0.04095	2.31278
26	12.75	0.03725	2.28235
27	13.25	0.03441	2.25191
28	13.75	0.03210	2.22146
29	14.25	0.03016	2.19101
30	14.75	0.02847	2.16054
31	15.25	0.02699	2.13005
32	15.75	0.02567	2.09955
33	16.25	0.02448	2.06902
34	16.75	0.02338	2.03847
35	17.25	0.02238	2.00790
36	17.75	0.02145	1.97729
37	18.25	0.02059	1.94666
38	18.75	0.01978	1.91599
39	19.25	0.01902	1.88528
40	19.75	0.01830	1.85454
41	20.25	0.01763	1.82375
42	20.75	0.01698	1.79292
43	21.25	0.01637	1.76205
44	21.75	0.01578	1.73113

SOIL HEAVE,FT: ADJACENT TO FOUNDATION= 0.17570 SUBSOIL= 0.24608

Table 8

Input and Output Data for Long Continuous Footing on Ground Surface

Input Data

```
=LONG CONTINUOUS ON GROUND SURFACE,  DGWT = 8 FT   MECH
NPROB,NSUCT,NBPRES,NNP,NBX,NMAT,DX
=2,0,3,17,1,2,.5
M,G,WC,EO,C,PHI,K
=1,2.7,23.,.8,,,
M,ALL,SP,CS,CC
=1,57.,2.2,.045,.27
M,G,WC,EO,C,PHI,K
=2,2.7,25.,.745,,,
M,ALL,SP,CS,CC
=2,60.,.66,.045,.27
ELEMENT,NO. OF SOIL
=1,1
=9,2
=16,2

XA,XF,DGWT,IOPTION,NOPT
=8.,.0,8.,0,1

Q,BLEN,BWID,LOCATION(CENTER=0,EDGE/CORNER=1)
=.072,.0,100.,1
```

Output Data

ELEMENT	DEPTH,FT	DELTA HEAVE,FT	EXCESS PORE PRESSURE,TSF
1	0.25	0.03832	2.13549
2	0.75	0.03432	2.10679
3	1.25	0.03141	2.07809
4	1.75	0.02911	2.04939
5	2.25	0.02722	2.02068
6	2.75	0.02561	1.99198
7	3.25	0.02420	1.96328
8	3.75	0.02296	1.93458
9	4.25	0.00903	0.36518
10	4.75	0.00794	0.33508
11	5.25	0.00694	0.30498
12	5.75	0.00603	0.27489
13	6.25	0.00519	0.24479
14	6.75	0.00441	0.21469
15	7.25	0.00367	0.18459
16	7.75	0.00299	0.15450

```
SOIL HEAVE,FT: ADJACENT TO FOUNDATION= 0.       SUBSOIL= 0.13968

*BYE
**resources used $   2.83, used to date $  589.92= 29%
**time sharing off at  10.481 on  06/04/80
```

Table 9

Shaft Foundation 30 Feet Deep

Input Data

```
 RUN
=SHAFT FOUNDATION, DGWT = 40 FT   SUCT  DRAINED DATA
NPROB,NSUCT,NBPRES,NNP,NBX,NMAT,DX
=11,1,1,41,31,5,1.
M,G,WC,EO,C,PHI,K
=1,2.7,23.,.8,.0,20.,1.
M,A,B,ALPHA,AKO,PI
=1,6.75,.25,1.,1.,39.
M,G,WC,EO,C,PHI,K
=2,2.7,25.,.745,.0,20.,1.
M,A,B,ALPHA,AKO,PI
=2,6.75,.25,1.,1.,40.
M,G,WC,EO,C,PHI,K
=3,2.75,30.,.825,.0,30.,1.
M,A,B,ALPHA,AKO,PI
=3,5.04,.17,.26,1.,14.
M,G,WC,EO,C,PHI,K
=4,2.76,29.,.828,1.,10.,2.
M,A,B,ALPHA,AKO,PI
=4,5.86,.18,1.,2.,55.
M,G,WC,EO,C,PHI,K
=5,2.76,29.,.828,1.,10.,2.
M,A,B,ALPHA,AKO,PI
=5,6.14,.19,1.,2.,55.
ELEMENT,NO. OF SOIL
=1,1
=5,2
=9,3
=13,4
=31,5
=40,5

XA,XF,DGWT,IOPTION,NOPT
=40.,.0,40.,0,1

PLOAD,AF,DP,DB
=10.,1.,2.,3.
```

(Continued)

Table 9 (Concluded)

FORCE RESTRAINING UPLIFT= 55.758 EXCESS= -120.696 TONS

SHAFT HEAVE= 1.16250 FEET

FORCE AT BOTTOM OF SHAFT= -166.454 TENSION= -166.454 TONS

ELEMENT	DEPTH,FT	DELTA HEAVE,FT	EXCESS PORE PRESSURE,TSF
1	0.50	0.15241	9.97117
2	1.50	0.12378	9.91352
3	2.50	0.11047	9.85586
4	3.50	0.10171	9.79820
5	4.50	0.06707	2.90143
6	5.50	0.06146	2.84099
7	6.50	0.05683	2.78055
8	7.50	0.05288	2.72011
9	8.50	0.01048	0.56540
10	9.50	0.01783	0.72427
11	10.50	0.01680	0.70835
12	11.50	0.01586	0.69244
13	12.50	0.06457	3.62349
14	13.50	0.04282	3.01758
15	14.50	0.04017	2.91613
16	15.50	0.03771	2.81469
17	16.50	0.03540	2.71325
18	17.50	0.03323	2.61181
19	18.50	0.03118	2.51036
20	19.50	0.02924	2.40892
21	20.50	0.02740	2.30748
22	21.50	0.02564	2.20603
23	22.50	0.02397	2.10459
24	23.50	0.02237	2.00315
25	24.50	0.02084	1.90171
26	25.50	0.01937	1.80026
27	26.50	0.01796	1.69882
28	27.50	0.01660	1.59738
29	28.50	0.01529	1.49593
30	29.50	0.01402	1.39449
31	30.50	0.01133	1.19369
32	31.50	0.01021	1.09224
33	32.50	0.00912	0.99080
34	33.50	0.00807	0.88936
35	34.50	0.00705	0.78791
36	35.50	0.00606	0.68647
37	36.50	0.00509	0.58503
38	37.50	0.00415	0.48359
39	38.50	0.00324	0.38214
40	39.50	0.00235	0.28070

SOIL HEAVE,FT: ADJACENT TO FOUNDATION= 1.30535 SUBSOIL= 0.06666

APPENDIX A: PROGRAM LISTING

```
C   PREDICTION OF HEAVE - HEAVE
C   BACED ON CONSTANT VOLUME SWELL/SWELL OVERBURDEN/SUCTION
C   DEVELOPED BY L. D. JOHNSON
    PARAMETER NL=10,NQ=81
    COMMON A(NL),B(NL),G(NL),WC(NL),EO(NL),SP(NL),AK(NL),CS(NL),
&   CC(NL),ALPHA(NL),AKO(NL),P(NQ),IE(NQ,1),N1,N2,NBX,NEL,IOPTION,
&   NOPT,DX,DXX,DGWT,PII,XA,XF,DELH,DELH1,DELH2
    DIMENSION PP(NQ),PI(NL),C(NL),PHI(NL)
        PRINT 1
      1 FORMAT(6HTITLE?)
   READ 3
    3   FORMAT(30H
    GAW=0.03125
    PII=3.14159265
    NP=1
    PRINT 5
      5 FORMAT(34HNPROB,NSUCT,NBPRES,NNP,NBX,NMAT,DX)
        READ,NPROB,NSUCT,NBPRES,NNP,NBX,NMAT,DX
    NEL=NNP-1
    14 PRINT 10
    10 FORMAT(17HM,G,WC,EO,C,PHI,K)
        READ,M,G(M),WC(M),EO(M),C(M),PHI(M),AK(M)
        PHI(M)=PHI(M)*PII/180.
        IF(AK(M).LT.0.01)AK(M)=1.0
    IF(NSUCT.EQ.1)GO TO 25
    PRINT 12
    12 FORMAT(10HM,SP,CS,CC)
        READ,M,SP(M),CS(M),CC(M)
    GO TO 20
    25    PRINT 8
     8 FORMAT(20HM,A,B,ALPHA,KT,PI,SP)
        READ,M,A(M),B(M),ALPHA(M),AKO(M),PI(M),SP(M)
    IF(ALPHA(M).LE.0.)GO TO 16
    GO TO 20
    16    ALPHA(M)=.0275*PI(M)-.125
    IF(PI(M).LE.5.)ALPHA(M)=0.0
        IF(PI(M).GE.40.)ALPHA(M)=1.
    20    IF(NMAT-M)26,27,14
    26    PRINT 17,M
    17    FORMAT(20H  ERROR IN MATERIAL ,I5)
    STOP
    27 L=0
    PRINT 30
    30    FORMAT(19HELEMENT,NO. OF SOIL)
    40    READ,N,IE(N,1)
    50    L=L+1
    IF(N-L)60,60,70
    70    IE(L,1)=IE(L-1,1)
    GO TO 50
    60    IF(NEL-L)80,80,40
    80    CONTINUE
        PRINT 81
```

```
1500    81 FORMAT(/,23HXA,XF,DGWT,IOPTION,NOPT)
1510       READ,XA,XF,DGWT,IOPTION,NOPT
1515       IF(NSUCT.EQ.0.AND.IOPTION.GT.1)PRINT 85
1517      85 FORMAT(30HIOPTION TOO LARGE; IOPTION = ?)
1518       IF(NSUCT.EQ.0.AND.IOPTION.GT.1)READ,IOPTION
1519       IF(IOPTION.GT.1)DGWT=FLOAT(NEL)*DX
1520       IF(NBPRES.EQ.1)GO TO 89
1530       PRINT 86
1540    86 FORMAT(/,44HQ,BLEN,BWID,LOCATION(CENTER=0,EDGE/CORNER=1))
1550       READ,Q,BLEN,BWID,MRECT
1560       GO TO 91
1570    89  PRINT 90
1580    90 FORMAT(/,14HPLOAD,AF,DP,DB)
1590       READ,PLOAD,AF,DP,DB
1592       IF(DP.GT.DB)PRINT 88
1593    88 FORMAT(51HDIAM SHAFT TOO LARGE; DIAM SHAFT = ?, DIAM BASE = ?)
1594       IF(DP.GT.DB)READ,DP,DB
1600    91 IF(IOPTION.LT.3)GO TO 92
1610       PRINT 101
1620   101 FORMAT(31HMATERIAL NO,FINAL TOTAL SUCTION)
1630   102 READ,M,CC(M)
1640       IF(NMAT-M)103,92,102
1650   103 PRINT 105,M
1660   105 FORMAT(20H  ERROR IN MATERIAL ,I5)
1670       GO TO 102
1690C   CALCULATION OF EFFECTIVE OVERBURDEN PRESSURE
1700    92 P(1)=0.0
1710       PP(1)=0.0
1720          DXX=DX
1730          DO 100 I=2,NNP
1740          MTYP=IE(I-1,1)
1750          WCC=WC(MTYP)/100.
1760          GAMM=G(MTYP)*GAW*(1.+WCC)/(1.+EO(MTYP))
1770       IF(DXX.GT.DGWT)GAMM=GAMM-GAW
1780          P(I)=P(I-1)+DX*GAMM
1790       PP(I)=P(I)
1800          DXX=DXX+DX
1810     100  CONTINUE
1820       IF(NSUCT.GT.0.AND.IOPTION.EQ.2)GO TO 111
1830       GO TO 112
1840   111 MATNEL=IE(NEL,1)
1845       IF(AKO(MATNEL).LT.0.01)AKO(MATNEL)=AK(MATNEL)
1850       F=(1.+2.*AKO(MATNEL))/3.
1860       TFI=A(MATNEL)-B(MATNEL)*WC(MATNEL)
1870       TFI=10.**TFI
1872       ALP=ALPHA(MATNEL)
1874       IF(DGWT.LT.FLOAT(NEL)*DX)ALP=1.0
1880       TFI=TFI-P(NNP)*F*ALPHA(MATNEL)
1890   112 DXX=0.0
1900       DO 114 I=1,NNP
1910       AI=I-1
1920       BN=DGWT/DX-AI
```

```
      IF(NSUCT.EQ.0.AND.DXX.LT.DGWT.AND.IOPTION.EQ.1)P(I)=P(I)+
&     BN*DX*GAW
      IF(NSUCT.EQ.0)GO TO 113
      IF(I.EQ.1)MTYP=IE(1,1)
      IF(I.GT.1)MTYP=IE(I-1,1)
      ALP=ALPHA(MTYP)
      IF(DXX.GT.DGWT)ALP=1.0
      TF=0.0
      IF(IOPTION.EQ.1.AND.DXX.LT.DGWT)TF=BN*DX*GAW
      IF(IOPTION.EQ.2)TF=TFI+(FLOAT(NEL)*DX-DXX)*GAW
      IF(AKO(MTYP).LT.0.01)AKO(MTYP)=AK(MTYP)
      F=(1.+2.*AKO(MTYP))/3.
      IF(IOPTION.EQ.3)TF=CC(MTYP)-P(I)*F*ALP
      P(I)=TF+P(I)*F*ALP
      IF(P(I).LT.0.0)PRINT 116,P(I),I
  116 FORMAT(31HNEGATIVE FINAL EFFECTIVE STRESS,F10.5,
&       12H  IN ELEMENT,I5)
  113 DXX=DXX+DX
  114 CONTINUE
      IF(NBPRES.GT.1)CALL SLAB(Q,NSUCT,BLEN,BWID,MRECT,NBPRES,PP(NBX))
      IF(NBPRES.GT.1)GO TO 210
C  CALCULATION OF RESTRAINING FORCE
         CON=DX*PII*DP*AF
      P1=0.0
         PR1=0.0
      PS1=0.0
      AN1=XA/DX
       N1=IFIX(AN1)+1
       N2=NBX-1
      IF(N1.GE.N2)GO TO 122
      DO 120 I=N1,N2
       MTYP=IE(I,1)
      PH=PHI(MTYP)
      TA=SIN(PH)/COS(PH)
      IF(NSUCT.EQ.0.OR.SP(MTYP).GT.0.01)GO TO 115
         TAUI=A(MTYP)-B(MTYP)*WC(MTYP)
         SP(MTYP)=10.**TAUI
    115  PS1=PS1+SP(MTYP)*CON
      PR=(PP(I)+PP(I+1))/2.
         PR1=PR1+PR*CON
      P1=P1+(PR*TA*AK(MTYP)+C(MTYP))*CON
  120 CONTINUE
    122  MAT=IE(NBX-1,1)
      QBU=7.*C(MAT)
      IF(PHI(MAT).LT.0.001)GO TO 125
      PH=PHI(MAT)
      TA=SIN(PH)/COS(PH)
      XNQ=(PH/2.)+45.*PII/180.
      XNQ=(1.+TA)*EXP(TA)*(SIN(XNQ)/COS(XNQ))**2.
      XNC=(XNQ-1.)/TA
      QBU=C(MAT)*XNC+P(NBX)*XNQ
  125 PRE=PLOAD+P1+QBU*PII*(DB**2.-DP**2.)/4.
```

```
      PRF=PRE/((FLOAT(N2)*DX-XF)*PII*DP)
C  CALCULATION OF EXCESS RESTRAINING FORCE AT BOTTOM OF PIER
        P2=0.0
      DELAV=0.0
          PR2=0.0
      PR3=0.0
      PS2=0.0
        CALL PSAD
        DO 150 I=N1,N2
        MTYP=IE(I,1)
      PH=PHI(MTYP)
      TA=SIN(PH)/COS(PH)
          IF(NSUCT.EQ.0)GO TO 145
      CS(MTYP)=ALPHA(MTYP)*B(MTYP)/(100.*B(MTYP))
          TAUI=A(MTYP)-B(MTYP)*WC(MTYP)
      IF(SP(MTYP).GT.0.01)GO TO 145
          SP(MTYP)=10.*TAUI
  145   PS2=PS2+SP(MTYP)*CON
      PR=(PP(I)+PP(I+1))/2.
      PRR=(P(I)+P(I+1))/2.
          PR2=PR2+PR*CON
      CT=CS(MTYP)
      IF(PRR.GT.SP(MTYP).AND.NSUCT.EQ.0)CT=CC(MTYP)
      CT=CT/(1.+EO(MTYP))
      IF(PRR.LT.PRF)PRR=PRF
      CA=SP(MTYP)/PRR
      DEL=CT*ALOG10(CA)*DX
      IF(DEL.LT.0.0.AND.DXX.GT.DGWT.AND.NSUCT.GT.0)DEL=DEL/ALPHA(MTYP)
      IF(DEL.LT.0.0.AND.IOPTION.LT.2.AND.NSUCT.GT.0)DEL=DEL/ALPHA(MTYP)
      P2=P2+(PR*TA*AK(MTYP)+C(MTYP))*CON
      DELAV=DELAV+DEL
  150 CONTINUE
          PST=PS1+PS2
          PRT=PR1+PR2
        CAT=P1+P2
         DPSR=PS2-PR2
          Q=PRE-DPSR
          IF(DPSR.GT.P2)Q=PRE-P2
         PRINT 160,PRE,Q
  160 FORMAT(/,25HFORCE RESTRAINING UPLIFT=,F10.3,9H  EXCESS=,
&     F10.3,6H  TONS)
      IF(Q.GT.0.0)DELAV=0.0
      PRINT 162,DELAV
  162 FORMAT(41HSHAFT HEAVE (EXCLUDING SUBSOIL MOVEMENT)=,
&     F13.5,6H  FEET)
C  CALCULATION OF FOUNDATION PRESSURE BENEATH FOOTING
      PSTPRT=PST-PRT
          QQ=PLOAD-PSTPRT
          IF(PSTPRT.GT.CAT)QQ=PLOAD-CAT
      IF(QQ.LT.0.0)QQ=0.00000
          T=PLOAD-DPSR
          IF(DPSR.GT.P2)T=PLOAD-P2
```

```
2915        IF(T.GT.0.0)T=0.00000
2920           PRINT 170,QQ,T
2930   170 FORMAT(25HFORCE AT BOTTOM OF SHAFT=,F10.3,9H TENSION= ,
2940&       F10.3,6H  TONS)
2942        IF(T.LT.-0.0001)ASTEEL=-0.03*T/DP**2.
2944        IF(T.LT.-0.0001)PRINT 180,ASTEEL
2946   180 FORMAT(34X,11HAREA STEEL=,F10.3,9H  PERCENT)
2950        IF(QQ.LE.0.01)GO TO 290
2960        BPRES=QQ+PP(NBX)*.7854*(DB**2.-DP**2.)
2970        BPRES=BPRES/(.7854*DB**2.)-PP(NBX)
2975        BPRE1=BPRES
2980         DXX=0.0
2990         DO 200 I=NBX,NNP
3000         IF(I.EQ.NBX)GO TO 201
3005        MTYP=IE(I-1,1)
3006        IF(NSUCT.EQ.1)ALP=ALPHA(MTYP)
3007        IF(NSUCT.EQ.1.AND.DXX.GT.DGWT)ALP=1.0
3008        IF(NSUCT.EQ.1)BPRES=BPRE1*ALP*(1.+2.*AKO(MTYP))/3.
3010        TP=1.+(DB/(2.*DXX))**2.
3020         TP=TP**1.5
3030        P(I)=P(I)+BPRES*(1.-1./TP)
3040         GO TO 205
3050   201 P(I)=P(I)+BPRES
3060    205 DXX=DXX+DX
3061   200 CONTINUE
3062C   CHECK FOR BEARING CAPACITY
3063   210 DO 250 I=NBX,NEL
3064        MTYP=IE(I,1)
3065        QBU=9.*C(MTYP)
3066        IF(PHI(MTYP).LT.0.001)GO TO 270
3067        PH=PHI(MTYP)
3068        TA=SIN(PH)/COS(PH)
3069        XNQ=(PH/2.)+45.*PII/180.
3070        XNQ=(1.+TA)*EXP(TA)*(SIN(XNQ)/COS(XNQ))**2.
3071        XNC=(XNQ-1.)/TA
3072        QBU=C(MTYP)*XNC+((PP(I)+PP(I+1))/2.)*XNQ
3073   270 IF(P(I).GT.QBU)PRINT 280,QBU,I
3074   280 FORMAT(19HBEARING CAPACITY OF,F10.3,18H  TSF EXCEEDED FOR,
3075&       8H ELEMENT,I5)
3076   250 CONTINUE
3077C   CALCULATION OF MOVEMENT FROM MODELS
3080    290 IF(NOPT.EQ.0)GO TO 300
3100        PRINT 305
3110    305 FORMAT(/,33HELEMENT  DEPTH,FT  DELTA HEAVE,FT,
3120&        26H  EXCESS PORE PRESSURE,TSF)
3130    300  IF(NSUCT.EQ.0)CALL MECH
3140         IF(NSUCT.GT.0)CALL SUCT
3141        DEL1=DELH1+DELH2
3143        PRINT 306,DELH1,DELH2,DEL1
3144   306 FORMAT(/,48HSOIL HEAVE NEXT TO FOUNDATION EXCLUDING SUBSOIL=,
3145&       F8.5,6H  FEET,/,17HSUBSOIL MOVEMENT=,31X,F8.5,6H  FEET,
3146&       /,20HTOTAL SOIL MOVEMENT=,28X,F8.5,6H  FEET)
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```
      IF(NBPRES.EQ.1)DEL2=DELAV+DELH2
      IF(NBPRES.EQ.1)PRINT 308,DEL2
  308 FORMAT(21HTOTAL SHAFT MOVEMENT=,27X,F8.5,6H  FEET)
      NP=NP+1
      IF(NP.GT.NPROB)GO TO 310
      GO TO 80
  310 STOP
      END
C
C
      SUBROUTINE MECH
      PARAMETER NL=10,NQ=81
      COMMON A(NL),B(NL),G(NL),WC(NL),EO(NL),SP(NL),AK(NL),CS(NL),
&     CC(NL),ALPHA(NL),AKO(NL),P(NQ),IE(NQ,1),N1,N2,NBX,NEL,IOPTION,
&     NOPT,DX,DXX,DGWT,PII,XA,XF,DELH,DELH1,DELH2
      DELH1=0.0
      CALL PSAD
      IF(N1.GE.N2)GO TO 50
      DO 10 I=N1,N2
      MTYP=IE(I,1)
      PR=(P(I)+P(I+1))/2.
      CA=SP(MTYP)/PR
      E=EO(MTYP)+CC(MTYP)*ALOG10(CA)
      IF(PR.LT.SP(MTYP))E=EO(MTYP)+CS(MTYP)*ALOG10(CA)
      DEL=(E-EO(MTYP))/(1.+EO(MTYP))
      IF(NOPT.EQ.0)GO TO 40
      DELP=SP(MTYP)-PR
      PRINT 200,I,DXX,DEL,DELP
   40 DELH1=DELH1+DX*DEL
      DXX=DXX+DX
   10 CONTINUE
   50 DELH2=0.0
      IF(NBX.GT.NEL)GO TO 175
      DXX=FLOAT(NBX)*DX-DX/2.
      DO 100 I=NBX,NEL
      MTYP=IE(I,1)
      PR=(P(I)+P(I+1))/2.
      CA=SP(MTYP)/PR
      E=EO(MTYP)+CC(MTYP)*ALOG10(CA)
      IF(PR.LE.SP(MTYP))E=EO(MTYP)+CS(MTYP)*ALOG10(CA)
      DEL=(E-EO(MTYP))/(1.+EO(MTYP))
      IF(NOPT.EQ.0)GO TO 125
      DELP=SP(MTYP)-PR
      PRINT 200,I,DXX,DEL,DELP
  125 DELH2=DELH2+DX*DEL
      DXX=DXX+DX
  100 CONTINUE
  200 FORMAT(I5,F10.2,F15.5,5X,F15.5)
  175 RETURN
      END
C
C
```

```
      SUBROUTINE SUCT
      PARAMETER NL=10,NQ=81
COMMON A(NL),B(NL),G(NL),WC(NL),EO(NL),SP(NL),AK(NL),CS(NL),
&CC(NL),ALPHA(NL),AKO(NL),P(NQ),IE(NQ,1),N1,N2,NBX,NEL,IOPTION,
&NOPT,DX,DXX,DGWT,PII,XA,XF,DELH,DELH1,DELH2
     DELH1=0.0
      CALL PSAD
     IF(N1.GE.N2)GO TO 50
      CALL HSUCT
      DELH1=DELH
 50   DELH2=0.0
     IF(NBX.GT.NEL)GO TO 175
     DXX=FLOAT(NBX)*DX-DX/2.
      N1=NBX
      N2=NEL
      CALL HSUCT
     DELH2=DELH
175  RETURN
      END
C
C
      SUBROUTINE HSUCT
      PARAMETER NL=10,NQ=81
COMMON A(NL),B(NL),G(NL),WC(NL),EO(NL),SP(NL),AK(NL),CS(NL),
&CC(NL),ALPHA(NL),AKO(NL),P(NQ),IE(NQ,1),N1,N2,NBX,NEL,IOPTION,
&NOPT,DX,DXX,DGWT,PII,XA,XF,DELH,DELH1,DELH2

      DELH=0.0
      DO 10 I=N1,N2
MTYP=IE(I,1)
     IF(AKO(MTYP).LT.0.01)AKO(MTYP)=AK(MTYP)
F=(1.+2.*AKO(MTYP))/3.
     PR=(P(I)+P(I+1))/2.
     TAUI=A(MTYP)-B(MTYP)*WC(MTYP)
TAUI=10.**TAUI
     UINIT=TAUI-PR
     CT=ALPHA(MTYP)*G(MTYP)/(100.*B(MTYP))
CT=CT/(1.+EO(MTYP))
     RTAU=TAUI/PR
     DEL=CT*ALOG10(RTAU)*DX
     IF(DEL.LT.0.0.AND.DXX.GT.DGWT)DEL=DEL/ALPHA(MTYP)
     IF(DEL.LT.0.0.AND.IOPTION.LT.2)DEL=DEL/ALPHA(MTYP)
        IF(NOPT.EQ.0)GO TO 33
     PRINT 30,I,DXX,DEL,UINIT
 30    FORMAT(I5,F10.2,F15.5,5X,F15.5)
 33  DELH=DELH+DEL
     DXX=DXX+DX
 10    CONTINUE
     RETURN
      END
C
C
```

```
      SUBROUTINE PSAD
      PARAMETER NL=10,NQ=81
  COMMON A(NL),B(NL),G(NL),WC(NL),EO(NL),SP(NL),AK(NL),CS(NL),
& CC(NL),ALPHA(NL),AKO(NL),P(NQ),IE(NQ,1),N1,N2,NBX,NEL,IOPTION,
& NOPT,DX,DXX,DGWT,PII,XA,XF,DELH,DELH1,DELH2
     AN1=XF/DX
      AN2=XA/DX
      N1=IFIX(AN1)+1
      N2=AN2
        DXX=XF+DX/2.
     N3=NBX-1
     IF(N2.GT.N3)N2=N3
     CONTINUE
     RETURN
     END
&
&
     SUBROUTINE SLAB(Q,NSUCT,BLEN,BWID,MRECT,NBPRES,WT)
     PARAMETER NL=10,NQ=81
  COMMON A(NL),B(NL),G(NL),WC(NL),EO(NL),SP(NL),AK(NL),CS(NL),
& CC(NL),ALPHA(NL),AKO(NL),P(NQ),IE(NQ,1),N1,N2,NBX,NEL,IOPTION,
& NOPT,DX,DXX,DGWT,PII,XA,XF,DELH,DELH1,DELH2
C     CALCULATION OF SURCHARGE PRESSURE FROM STRUCTURE
     NNP=NEL+1
     ANBX=FLOAT(NBX)*DX
     DXX=0.0
     BPRE1=Q-WT
     BPRES=BPRE1
     DO 10 I=NBX,NNP
     IF(DXX.LT.0.01)GO TO 30
     MTYP=IE(I-1,1)
     IF(NSUCT.EQ.1)ALP=ALPHA(MTYP)
     IF(NSUCT.EQ.1.AND.DXX.GT.DGWT)ALP=1.0
     IF(NSUCT.EQ.1)BPRES=BPRE1*ALP*(1.+2.*AKO(MTYP))/3.
     IF(NBPRES.EQ.3)GO TO 20
     IF(DXX.LT.0.01)GO TO 30
     BL=BLEN
     BW=BWID
     BPR=BPRES
     IF(MRECT.EQ.1)GO TO 40
     BL=BLEN/2.
     BW=BWID/2.
  40  VE2=(BL**2.+BW**2.+DXX**2.)/(DXX**2.)
     VE=VE2**0.5
     AN=BL*BW/(DXX**2.)
     AN2=AN**2.
     ENM=(2.*AN*VE/(VE2+AN2))*(VE2+1.)/VE2
     FNM=2.*AN*VE/(VE2-AN2)
     IF(MRECT.EQ.1)BPR=BPRES/4.
     AB=ATAN(FNM)
     IF(FNM.LT.0.)AB=PII+AB
     P(I)=P(I)+BPR*(ENM+AB)/PII
```

```
      GO TO 70
   20  DB=DXX/BWID
      PS=-.157-.22*DB
      IF(MRECT.EQ.0.AND.DB.LT.2.5)PS=-.28*DB
      PS=10.**PS
      P(I)=P(I)+BPRES*PS
      GO TO 70
   30  P(I)=P(I)+BPRES
   70  DXX=DXX+DX
   10  CONTINUE
      RETURN
      END
```

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